

Integrating Tower EC, Remote Sensing and Ecosystem Modeling to Monitor Arctic-boreal CO₂ & CH₄ Fluxes



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VITAL SIGNS:

Taking the Pulse of Our Planet

Important in Rapidly Changing Arctic Environments

A cartoon illustration of a man in a green military-style uniform with gold epaulettes and a blue sash. He is standing on the left pan of a teal-colored mechanical balance scale. On the right pan, there is a yellow tape measure with the number '1' at the top. The scale's beam is tilted downwards towards the tape measure, indicating it is heavier. The artist's signature 'con' is visible at the bottom right of the drawing.

One accurate
measurement is worth
a thousand
expert opinions

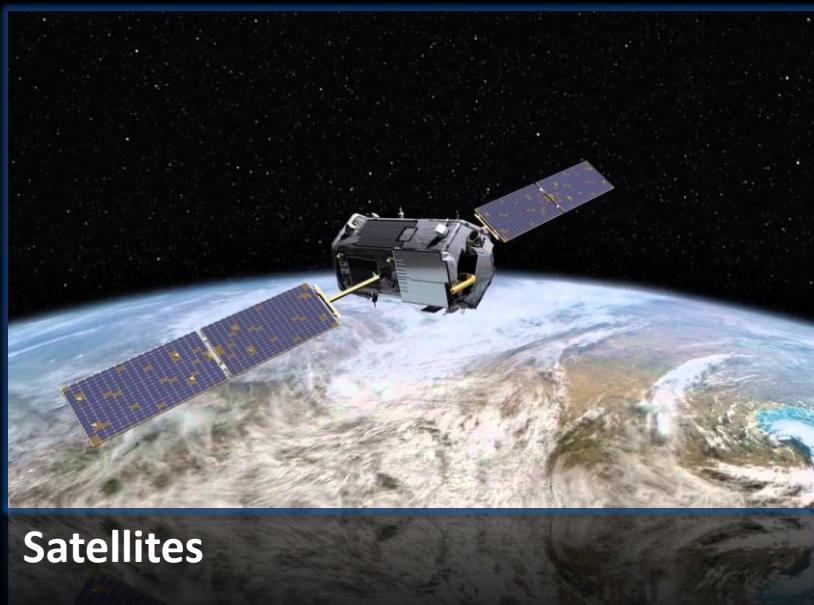
Grace Hopper

But the Arctic is a Big Place!



And In Situ Measurements are Expensive

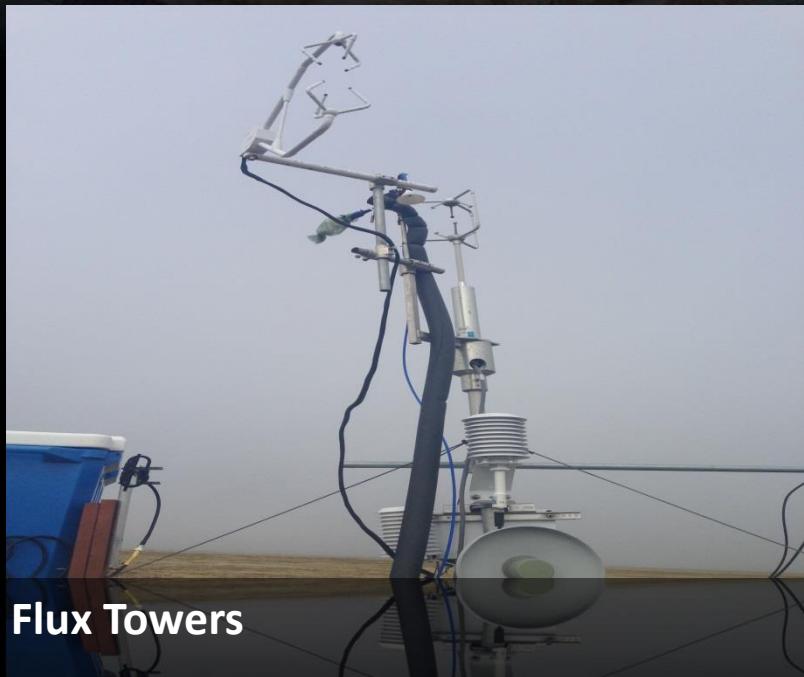
We Need Repeated Measurements at Various Scales



Satellites



Airborne Remote Sensing

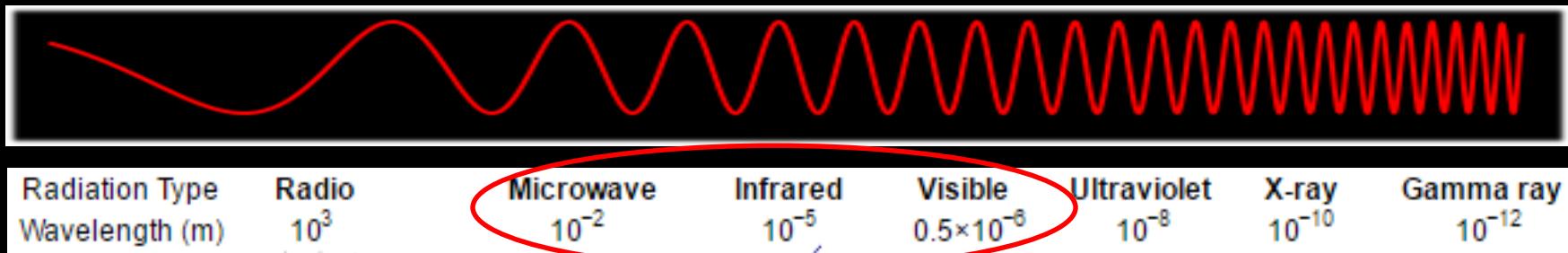
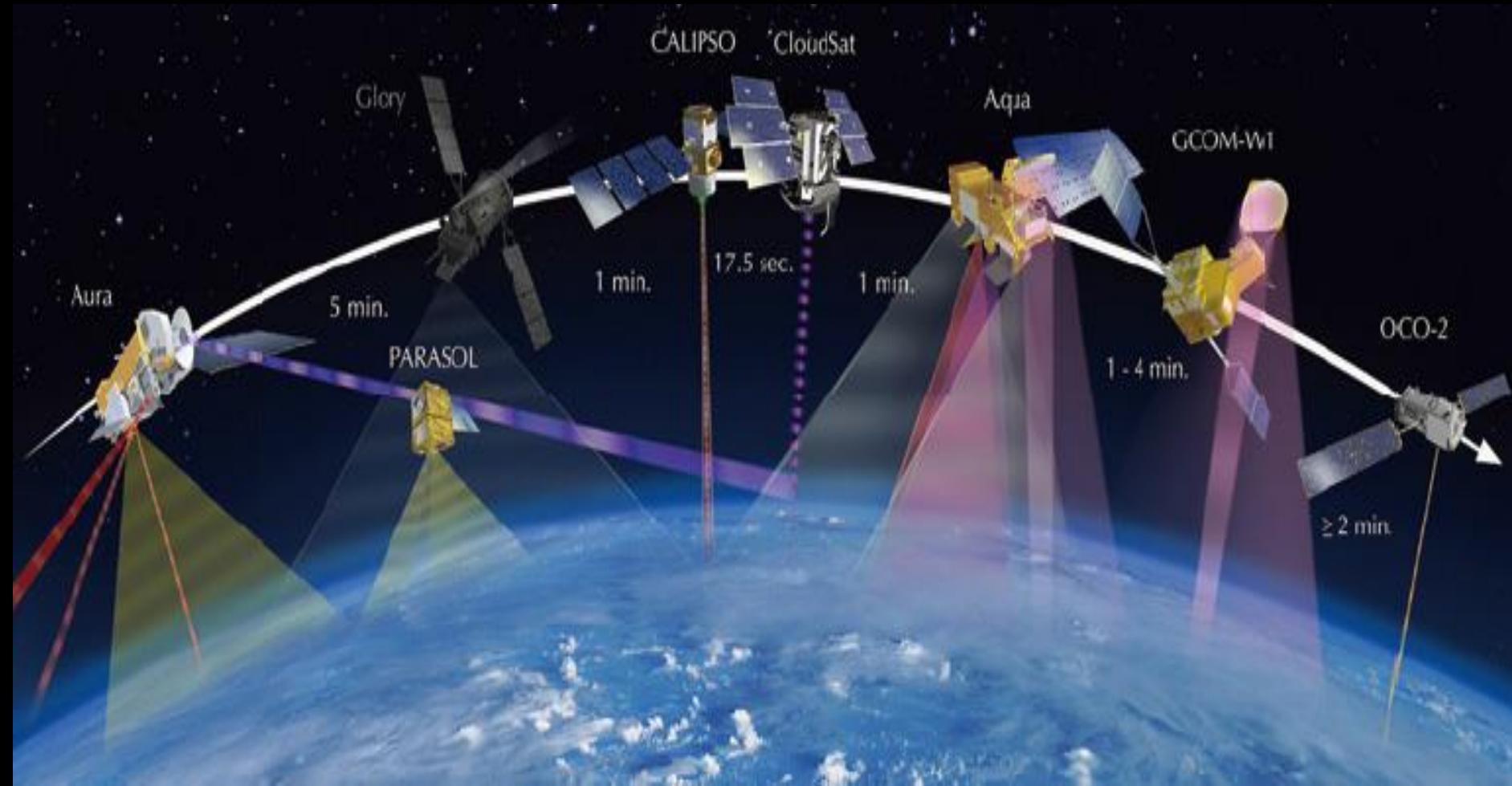


Flux Towers



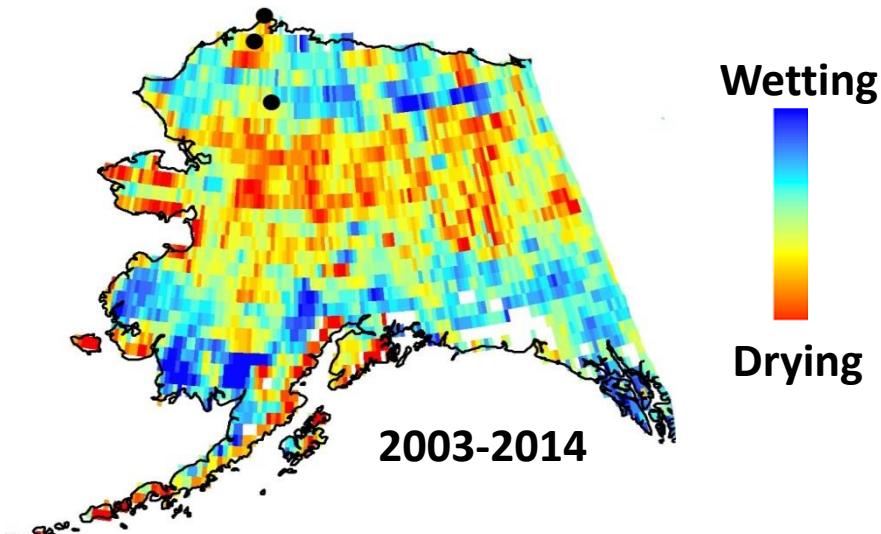
Flux Chambers

Using a Suite of Satellite Observations to Monitor Change

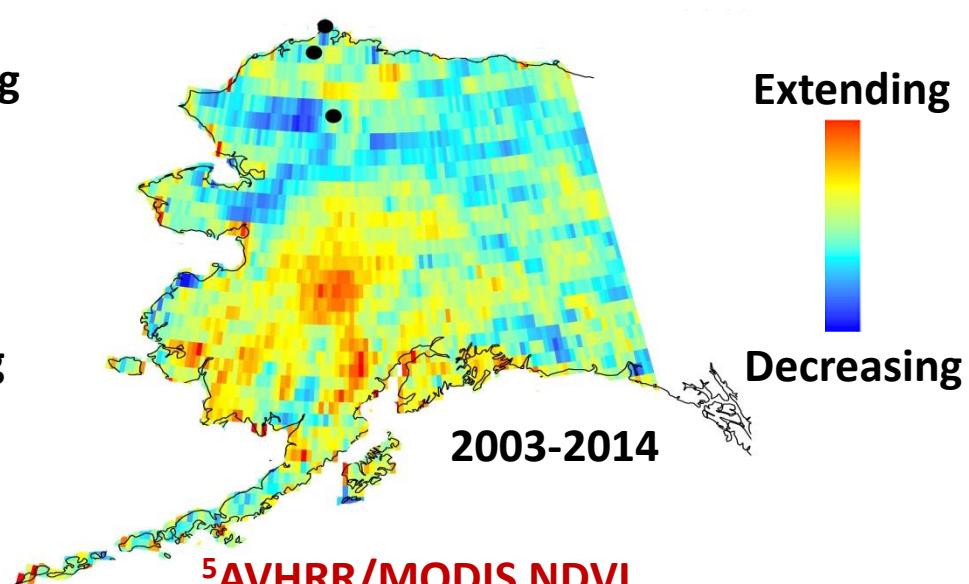


Satellite Observations: Monitoring Regional Change

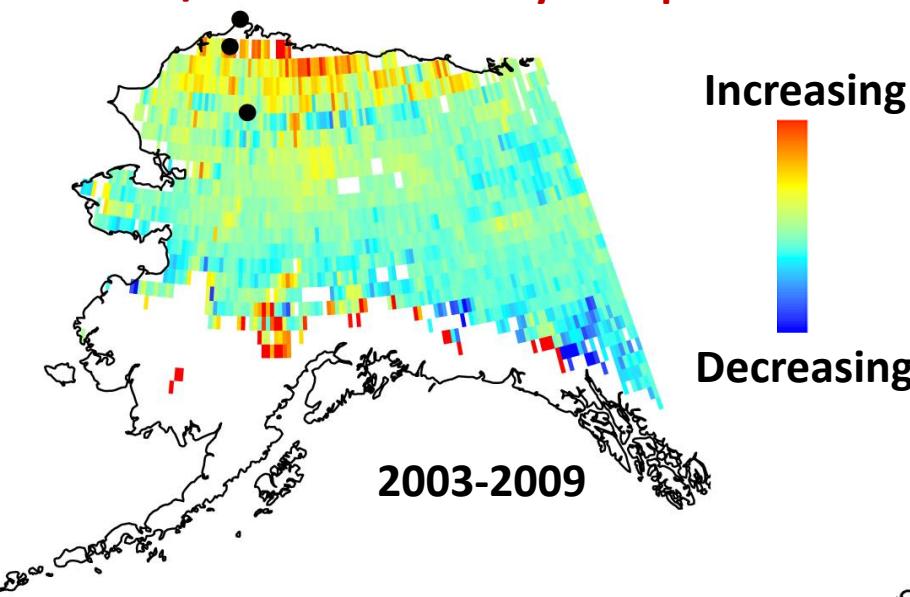
^{1,2}AMSR Surface Water



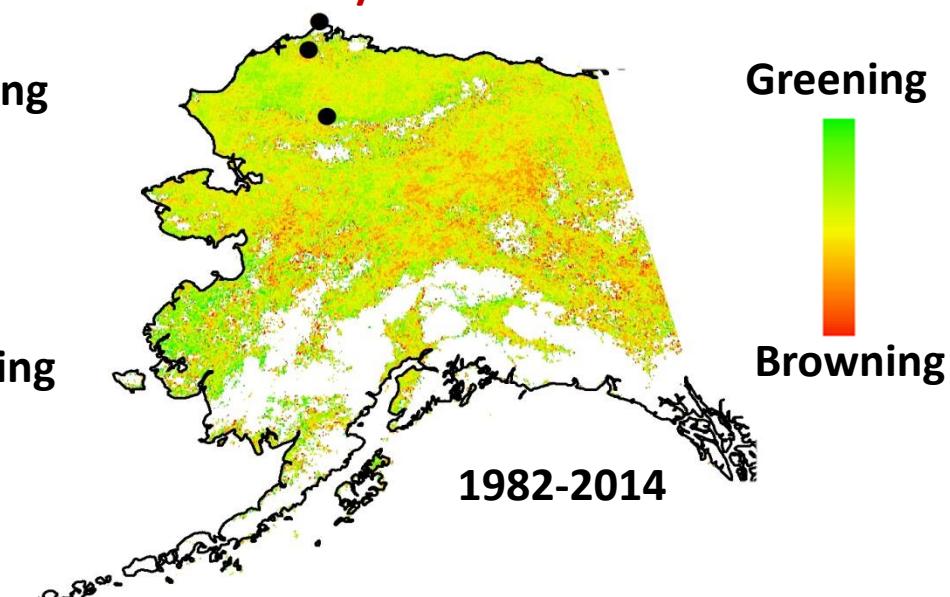
³AMSR Non-Frozen Season



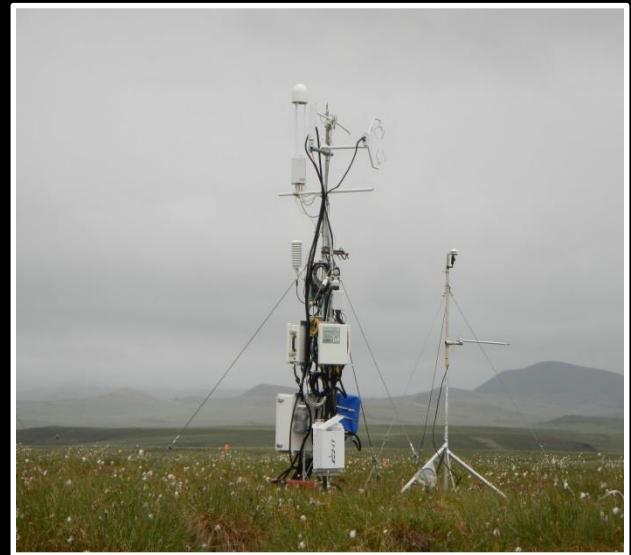
⁴SSMI/MODIS Active Layer Depth



⁵AVHRR/MODIS NDVI



EC Tower Flux Measurements



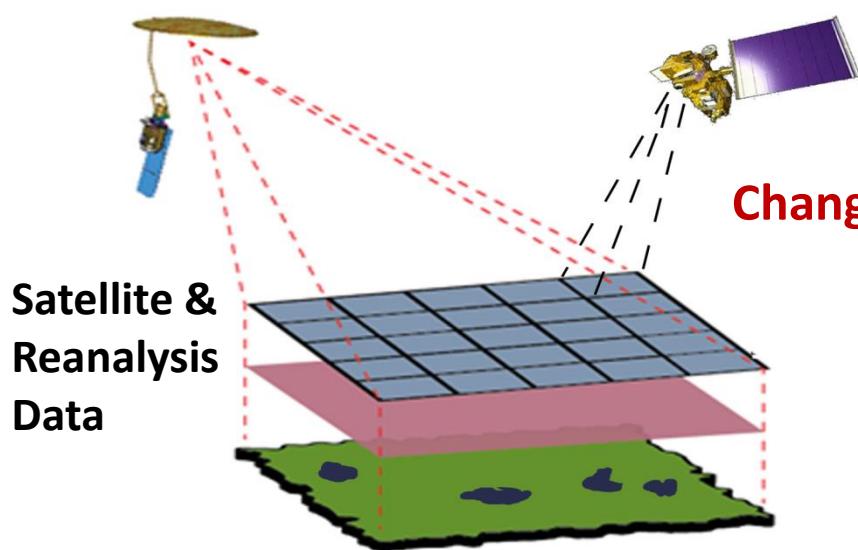
Critical! Needed to Calibrate/Validate Ecosystem Models

Primary Research Objectives

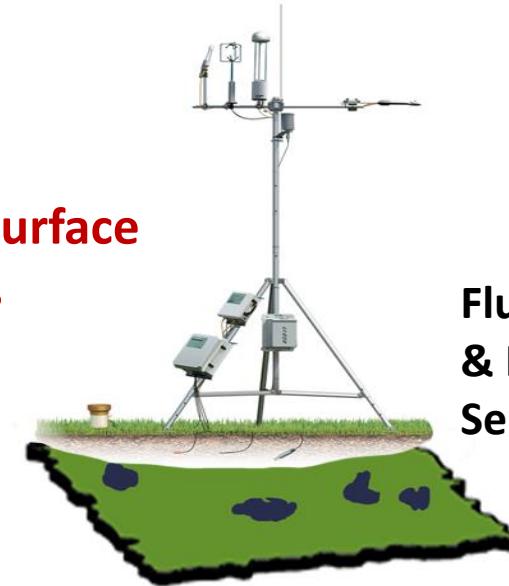
Use satellite remote sensing & tower EC data to:

- **Identify patterns in Arctic-boreal CO₂, CH₄ fluxes**
 - Environmental drivers of GPP vs. Reco
 - Changes in landscape carbon sink & source activity
 - High-res (daily; ≤ 9 km) carbon maps
- **Determine wetland CH₄ contributions**
 - Regional emission magnitudes; GHG budget impact
 - Interannual changes in wetland extent
 - Inundated landscape constraints vs.
sub-surface water table & soil moisture
- **Assess regional landscape change & vulnerability**
 - Surface & soil wetting/drying vs. temperature controls
 - Active layer variability
 - Vegetation start & length of season
 - Snow cover properties & effects on carbon cycling





Changing Earth Surface Properties

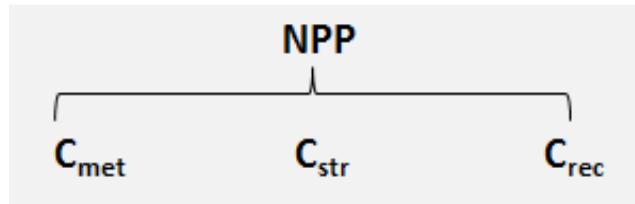


Integrate with Ecosystem TCF Modeling for Regional Carbon Monitoring^(1,2)

$$GPP = \varepsilon \times PAR \times FPAR$$

$$\varepsilon = \varepsilon_{\max} \times f(VPD) \times f(T_{min}) \times f(\theta)$$

$$R_{aut} = (1-CUE) \times GPP$$

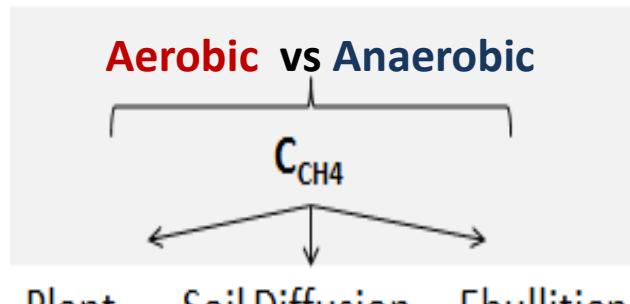


$$R_{het} = f(C_{pool}, T_s, \theta)$$



$$R_{CH4} = (R_o \times \varphi_s) \times C_{pool} \times Q_{10}^{(T_s - T_p)/10}$$

Aerobic vs Anaerobic



¹Watts et al. 2014 *Biogeosciences*

²Kimball et al. 2015 *SMAP L4_C User Guide*

TCF (SMAP L4C) CO₂ Model

$$\text{NEE}(t) = \frac{d\text{SOC}}{dt} = \text{RECO}(t) - \text{GPP}(t)$$

$$\text{RHET}(t) + \text{RAUT}(t)$$

$$k_{\max} * \text{SOC}(t) * \text{Scalars}$$

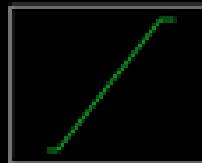
$$\epsilon_{\max} * \boxed{\text{Fpar}} * \text{Par} * \text{Scalars}$$



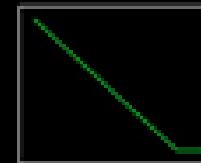
Tsoil



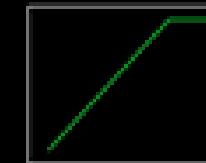
SMSF



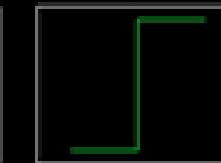
Tmin



VPD



SMRZ



F_T

Environmental Scalars: Satellite RS
(e.g. SMAP, AMSR) & Reanalysis Inputs

MODIS
VIS/NIR

TCF CH₄ Model

1. Wetland CH₄ production



Satellite and/or Reanalysis Inputs

$$R_{CH_4} = (R_o \times \varphi_s) C_{met} \times Q_{10p}^{\frac{(Ts - Tref)}{10}}$$

2. Three flux pathways

CO₂ Model Inputs

- **Vegetation**

$$F_{plant} = C_{CH_4} \times C_p \times S_{grow} \times \lambda \times P_{trans} \times (1 - P_{ox})$$

$$S_{grow} = f(GPP), \quad \lambda = f(u_m)$$

- **Diffusion**

$$F_{diff} = (C_{CH_4} \times \tau \times D_e (C_{CH_4} - Air_{CH_4}) (1 - \theta)) - R_{ox}$$

$$\tau = f(T_s), \quad D_e = f(\theta), \quad R_{ox} = f(T_s)$$

- **Ebullition**

$$F_{ebull} = (C_e - \varphi_s) \times (C_{CH_4} - v_e)$$

NASA ABoVE EC Tower Sites

Climate Variability

	BEO/BES	ATQ	IVO
Elev. (m)	6	15	568
MAT (°C)	-12.6	-9.7	-7.9
MSP (mm)	72	100	210
ALD (cm)	-36	-50	-60

Vegetation Communities

BES/BEO: Inundated & polygonal tundra (grass, sedge, moss)

ATQ: Moist sedge tundra & tussock

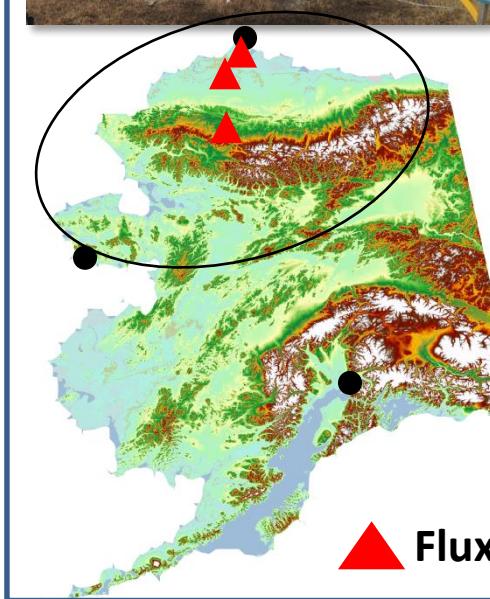
IVO: Tussock tundra & dwarf shrub, moss and lichen



Barrow
BES/BEO



Atqasuk (ATQ)

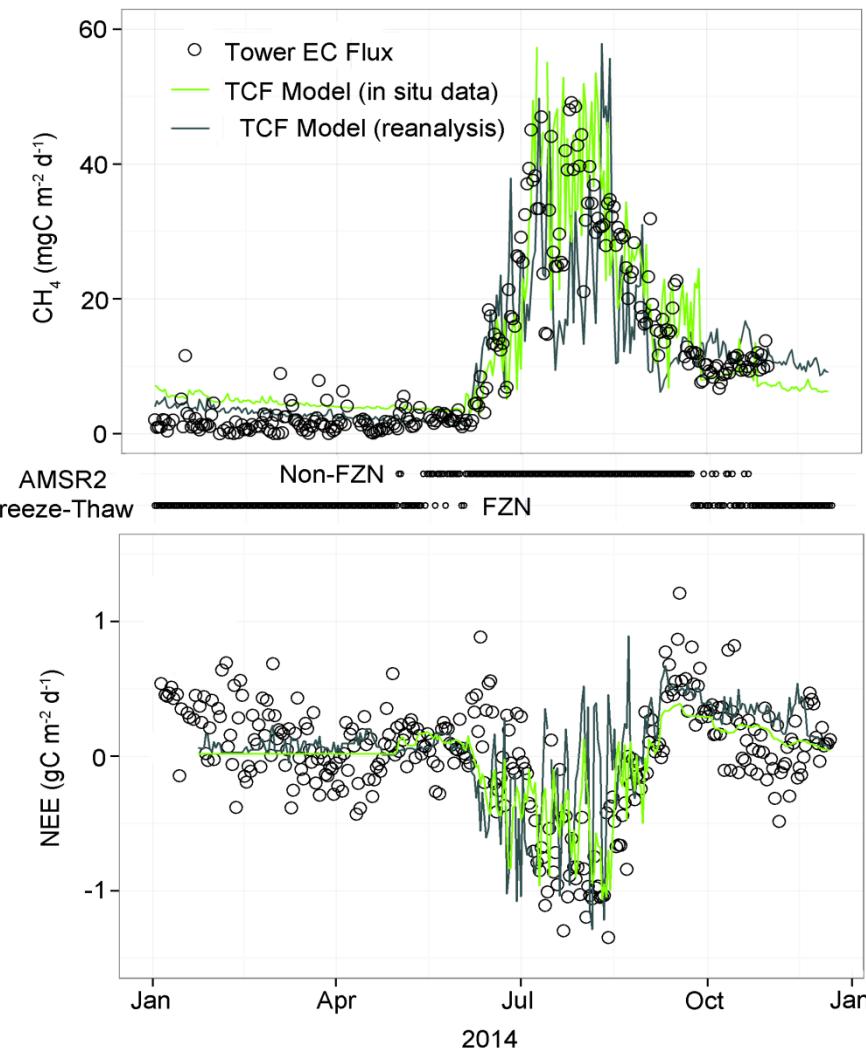


Flux Towers

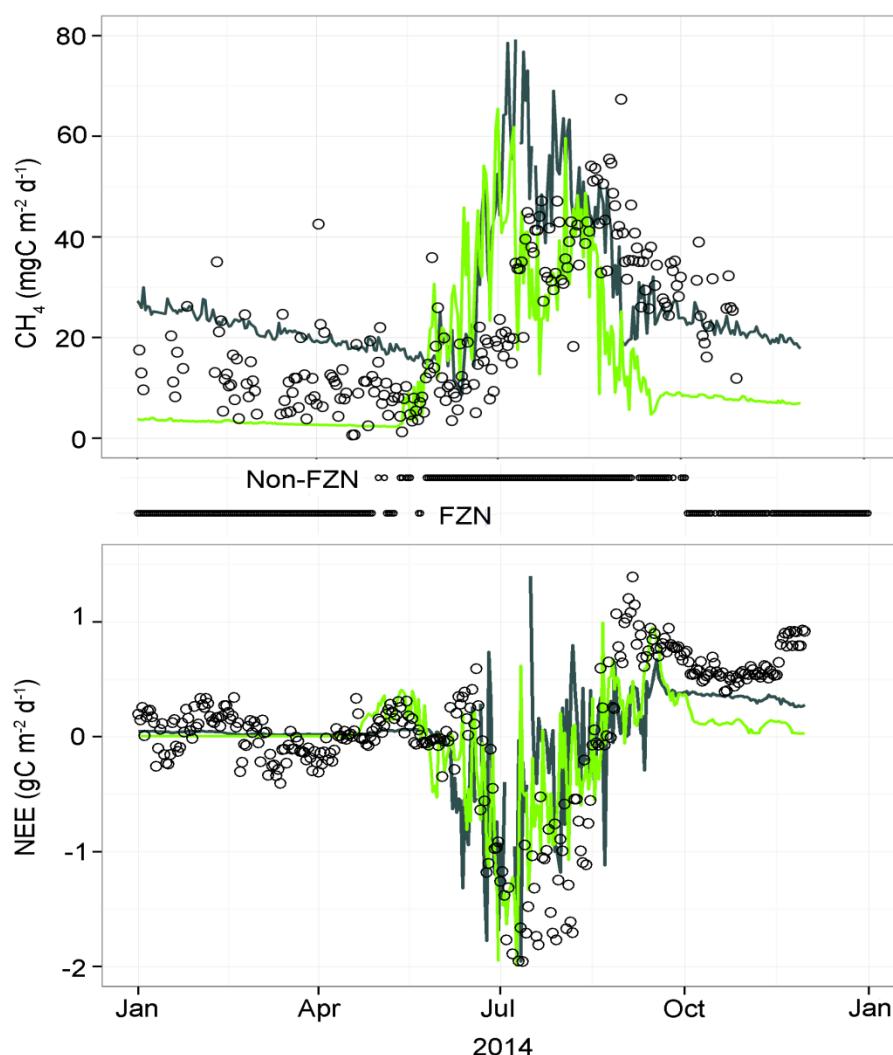


NASA ABoVE TCF Ecosystem Modeling

BES



IVO



Wet Sedge

NEE: $-4 \text{ g C m}^{-2} \text{ yr}^{-1}$
CH₄: $3.5 \text{ g C m}^{-2} \text{ yr}^{-1}$

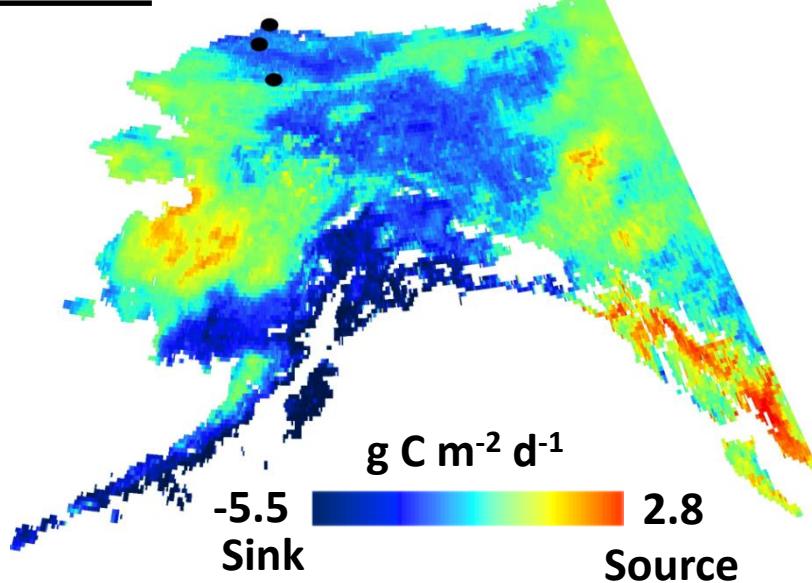
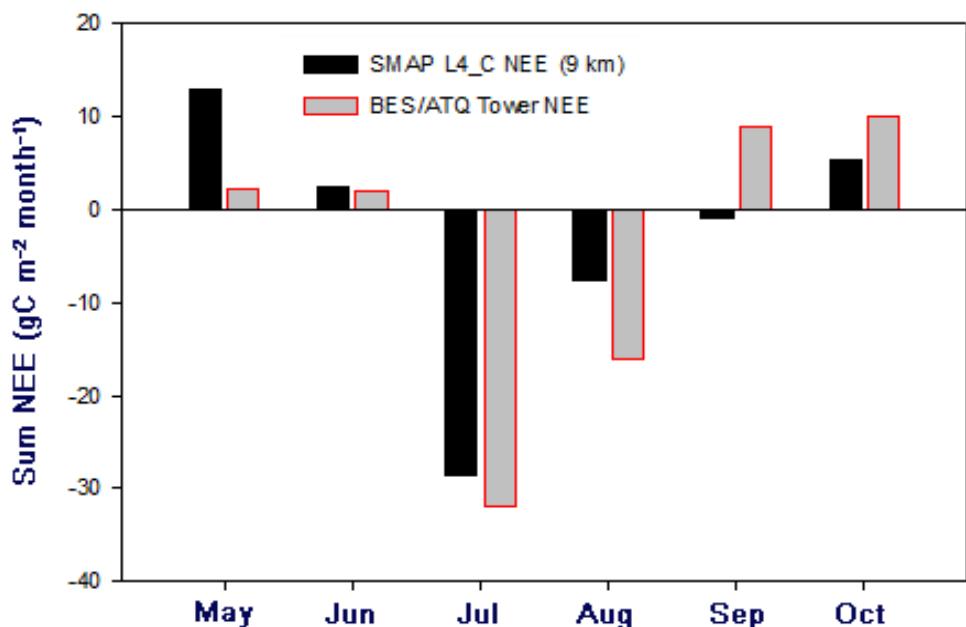
Tussock

NEE: $-12 \text{ g C m}^{-2} \text{ yr}^{-1}$
CH₄: $6.5 \text{ g C m}^{-2} \text{ yr}^{-1}$

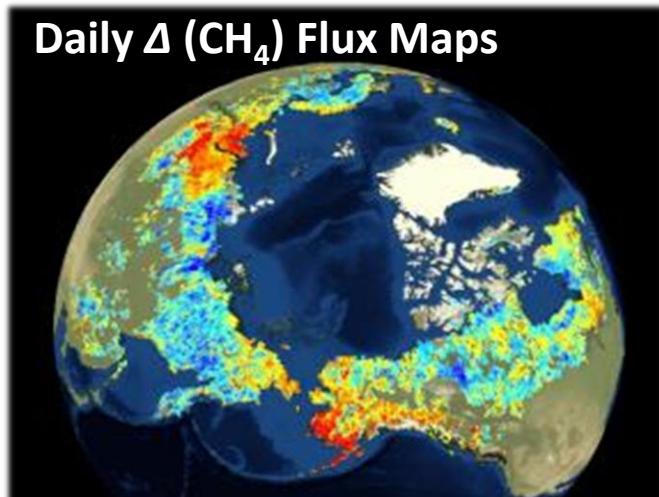
Model Scaling of Carbon Fluxes

SMAP L4C NEE (8/12/15)

- **¹Beta release of NASA SMAP L4 Carbon Maps**
 - Radiometer informed soil moisture & temp.
 - 9 km spatial res. & daily NEE, GPP, Reco fluxes
 - Data from April 2015 onward



Arctic-boreal TCF CH₄ Modeling



- **Off-line 1 km TCF CO₂ + CH₄ Flux Maps (In Progress)**
 - Regional validation using EC tower data (32+ sites; 15 have CH₄ records)
 - Evaluation against airborne & tall tower obs., inverse models

¹SMAP L4 Global Daily Carbon Products: <http://nsidc.org/data/SPL4CMDL>

Challenges for Regional Modeling

- **Flux tower data**
 - Accessibility (not all datasets on Fluxnet, etc.)
 - Flux processing, QC, & gap-filling
 - Sparse pan-Arctic tower network; data overlap needed
 - Limitations to tower longevity (\$)
- **Modeling**
 - Arctic-boreal wetland/veg. maps; land cover classifications often inconsistent
 - Reanalysis data are spatially coarse (0.5°); 3-9 km ideal
 - Water inundation maps are coarse (e.g. 6-25 km)
- **Surface flux maps vs. atmospheric observations**
 - Available airborne observations limited in space & time
 - Regional inverse modeling (tall towers?)
 - Gauging CH_4 contributions from lakes & rivers





Thank You!